Cement Thickness of Inlay Restorations Made of Lithium Disilicate, Polymer-Infiltrated Ceramic and Nano-Ceramic CAD/CAM Materials Evaluated Using 3D X-Ray Micro-Computed Tomography

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Abstract: PURPOSE To evaluate the marginal and internal cement thicknesses of inlay restorations made of various CAD/CAM materials using 3D X-ray micro-computed tomography (micro-CT) technique. MATERIALS AND METHODS Caries-free extracted mandibular molars (N = 30) with similar size were randomly assigned to three groups (N = 10 per group). Mesio-occlusal-distal (MOD) cavities were prepared, and inlay restorations were obtained by milling out CAD/CAM materials namely, (a) IPS: monolithic lithium disilicate (control), (b) VE: polymer-infiltrated ceramic, and (c) CS: nano-ceramic using a CAM unit. Marginal and internal cement thicknesses were measured using 3D micro-CT. Data were analyzed using 1-way ANOVA and Tukey's tests (alpha = 0.05). RESULTS The mean marginal and internal cement thickness were not significant in all inlay materials ($p > 0.05$). Mean marginal cement thickness (m) was the lowest for the IPS group (67.54 ± 10.16) followed by VE (84.09 ± 3.94) and CS (95.18 ± 10.58) ($p > 0.05$). The internal cement thickness (m) was the lowest in the CS group (54.85 ± 6.94) followed by IPS (60.58 ± 9.22) and VE (77.53 ± 12.13) ($p > 0.05$). CONCLUSION Marginal and internal cement thicknesses of MOD inlays made of monolithic lithium disilicate, polymer-infiltrated ceramic, and nano-ceramic CAD/CAM materials were similar and all less than 100 m, which could be considered clinically acceptable. CLINICAL SIGNIFICANCE MOD inlays made of different CAD/CAM materials presented similar cement thickness, less than 100 m.

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Cement Thickness of Inlay Restorations Made of Lithium disilicate, Polymer-infiltrated Ceramic and Nano-ceramic CAD/CAM Materials Evaluated Using 3D X-ray Micro-computed Tomography

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Short title: *Micro-CT evaluation of cement thickness in inlay restorations*

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Abstract

Purpose: The aim of this study was to evaluate the marginal and internal cement thicknesses of inlay restorations made of various CAD/CAM materials using 3D X-ray micro-computed tomography (micro-CT) technique.

Material and Methods: Caries-free extracted mandibular molars (N=30) with similar size were randomly assigned to three groups (N=10 per group). Mesio-occlusal-distal (MOD) cavities were prepared and inlay restorations were obtained by milling out CAD/CAM materials namely, a) IPS: monolithic lithium disilicate (IPS emax CAD; control), b) VE: Polymer-infiltrated ceramic (Vita Enamic) and c) CS: Nano-ceramic (Cerasmart) using a CAM unit. Marginal and internal cement thicknesses were measured using 3D micro-CT (SkyScan 1172, Bruker-micro-CT). Data were analyzed using 1-way ANOVA and Tukey's tests (alpha=0.05).

Results: The mean marginal and internal cement thickness were not significant in all inlay materials ($p > 0.05$). Mean marginal cement thickness (μm) was the lowest for the IPS group (67.54±10.16) followed by VE (84.09±3.94) and CS (95.18±10.58) ($p > 0.05$). The internal cement thickness (μm) was the lowest in CS group (54.85±6.94) followed by IPS (60.58±9.22) and VE (77.53±12.13) ($p > 0.05$).

Conclusion: Marginal and internal cement thicknesses of MOD inlays made of monolithic lithium disilicate, polymer-infiltrated ceramic and nano-ceramic CAD/CAM materials were similar being less than 100 μm, which could be considered clinically acceptable.

Clinical Significance: MOD inlays made of different CAD/CAM materials presented similar cement thickness being less than 100 μm.

Keywords CAD/CAM; Cement thickness; Micro-CT

Introduction

Despite the advances made in modern dentistry, dental caries remains a significant problem and currently represents one of the main causes of tooth loss. In contemporary practices, moderate Class I and II carious lesions could be restored using inlay or onlay restorations[1-4] that could be fabricated from a range of materials including alloy, ceramic, or resin composite.[5] Long-term clinical studies still consider cast gold partial coverage as the model of excellence for restoring teeth with caries in posterior teeth. However, recently, novel materials and techniques have been introduced as non-metallic tooth-colored materials for posterior restorations. One such material is monolithic lithium disilicate all-ceramic produced using CAD-CAM technologies that also present high fracture resistance.[6,7]

Several factors could directly influence the longevity of indirect ceramic restorations among which the quality of marginal seal and the thickness of the luting agent seems to be most relevant.[x] Marginal seal has the most substantial impact on the longevity as it ensures resistance to secondary carries and microleakage. On the other hand, the gap between the restoration and the tooth surface, filled with cement in the three-dimensional plane is also of significance for the durability of the restorations. In order to function effectively, the restoration needs mechanical support provided by the tooth substance, which becomes more crucial in the posterior teeth.[8-10] Overall, three-dimensional fit is directly affected by the thickness of the cement layer. In this regard, three factors need to be taken into consideration when placing restorations, namely, the thickness, chemical structure and elastic modulus of the restoration and the cement.[11-13]

Marginal and internal cement thickness of a restoration could be assessed using different methods based on sectioning, replica or X-ray micro-computed tomography (micro-CT) techniques, where the latter two are considered less invasive.[14] Among various methods that are employed to evaluate the fit of dental reconstructions, micro-CT is becoming increasingly common.[15-22]

Recently introduced CAD/CAM materials combine the durability and long-lasting colour of ceramics with the benefits of resin composite materials. Current studies reported optimal marginal and internal cement thickness for such materials ranging between 20 and 200 µm.[8,23-28] The manufacturers however claim cement thickness within clinically acceptable levels.[29,30] In fact, cement thickness below 200 µm could more effectively withstand wear of the cement at the restoration margins.[31,32]

The wide range of cement thickness with the recent CAD/CAM materials also relates to the measurement method. To date, micro-CT technique was not employed to assess the internal and marginal cement thickness of partial coverage restorations made of recent CAD/CAM materials. Therefore, the objective of this study was to evaluate the marginal and internal cement thickness of inlay restorations made of monolithic lithium disilicate, polymer-infiltrated ceramic and nano-ceramic CAD/CAM materials. The null hypothesis tested was that there would be no significant difference in marginal and internal cement thickness of inlay restorations fabricated from different CAD/CAM materials.

Materials and Methods

Preparation of specimens

The Ethic Committee of Kirikkale University, Faculty of Medicine, approved this research project. Caries-free extracted mandibular molars (N=30) with similar size were selected. The teeth were initially examined under x10 magnification using loops and only those deemed to be free from any hypoplastic defects and cracks were selected. The teeth were thoroughly cleaned from soft tissues and stored in 0.1% thymol solution at room temperature until experiments.[33] The apical parts of all teeth were embedded in an auto-polymerizing resin until the cement-enamel junction (CEJ) (Paladent RR, Heraeus Kulzer GmbH, Hanau, Germany).

The teeth were divided into three groups (n=10 per group) and received an inlay manufactured from one of the following CAD/CAM materials, namely a) IPS: monolithic lithium disilicate (IPS e-max CAD, Ivoclar Vivadent, Schaan, Liechtenstein; Control group), b) VE: Polymer-infiltrated ceramic (Vita Enamic, VITA Zahnfabrik, GmbH & Co, Bad Säckingen, Germany) and c) CS: Nano-ceramic (Cerasmart, GC Dental

Products, Tokyo, Japan) (Table 1). A mesio-occlusal-distal (MOD) inlay cavity was prepared in each tooth with 3 mm isthmus width and 2.5 mm cavity depth. Cavities were prepared 1 mm above the CEJ at an overall preparation angle of 10 degrees towards the occlusal aspect and rounded shoulder.[27,33,34] One single operator prepared the cavities using a dental surveyor (Paraflex, BEGO GmbH, Bremen, Germany). The teeth were first prepared using 80 μm grit diamond burs (837KR.314.012*, 847KR.314.016*, Komet, Dental, Brasseler, Lemgo, Germany) and finished with 30-40 μm grit diamond burs (8837KR.314.012*, 8847KR.314.016*, 8390.204.016*, Komet).[35]

As for milling parameters, 40 μm for the spacer and 20 μm for the cement gap were established.[36] Inlay cavities were then scanned using a laboratory scanner (D710 3D Scanner, 3Shape, Copenhagen, Denmark) and CAD software (3D Dental System 2015, 3Shape) was used in order to design the inlays. A CAM unit (Coritec 550i, Imes-icor GmbH, Eiterfeld, Germany) milled the inlays out of the test materials for each tooth.

Adhesive cementation

Inlay restorations were adhesively cemented (Panavia F2.0, Kuraray Noritake Dental Inc., City, Japan) to the corresponding cavities following the manufacturer`s instructions. Initially, intaglio surfaces of the inlays were air-abraded (50 micron $Al_2 0_3$, Microetcher, Danville Engineering, CA, USA) and then etched with 40% phosphoric acid (K Etchant gel, Kuraray Noritake Dental Inc.) for 5 s. Equal amounts of silane was mixed (Clearfil SE Bond, Porcelain Bond Activator, Kuraray Noritake Dental Inc.) and applied one coat using a microbrush. The tooth surface was conditioned using a self-etch primer (ED Primer A and B, Kuraray) for 30 s and air-dried gently with oil-free air. Equal amounts of the base and activator of dual-polymerized resin cement was mixed for 20 s and the mixture of paste was applied on the intaglio surface of the inlays. The inlay was cemented with the aid of a sticky holder (Vivastick, Ivoclar Vivadent) under 50 N and excess cement was removed using dental probe and microbrush. The inlay was then photo-polymerized from mesial, distal and occlusal aspects for 20 s per surface using an LED unit (Bluephase, Ivoclar Vivadent; Light output: 1200 mw/cm^2). Glycerine gel was applied at the margins (Oxyguard, Kuraray Noritake Dental Inc.), waited for 60 s and rinsed with copious water.

Cement thickness measurement

The cement thickness at the margins and internal surface of the inlays were measured using high-resolution 3D micro-CT (SkyScan 1172, Bruker-micro-CT, Kontich, Belgium). The X-ray tube was operated at 100 kV and 100 μA using a 0.5 mm Al+Cu filter at a resolution of 10 μm pixels. Each specimen was scanned for a total of 60 minutes at rotation 180° around the vertical axis. The camera exposure time was 1400 ms, with a rotation step of 0.40, average frame of 3 and random movement of 20 mm. System reconstruction software (NRecon v.1.6.3, SkyScan, Brucker-micro-CT) was then employed in order to reconstruct the axial cross-sections of the resulting two-dimensional images (8-bit TIFF) with a beam hardening correction of 55%, smoothing of 3, and an attenuation coefficient range of 0-0.064000. Thereafter, 3D reconstructions were developed using the softwares to produce the linear and volumetric analysis (CTAn v.1.12 and CT Vol v.2.2.1, Skyscan, Bruker-micro-CT). Finallly, gingival cement thickness was calculated for marginal area and mean axial and pulpal cement thickness were calculated for internal cement thickness (Fig. 1).

Statistical analysis

Statistical analysis was performed with SPSS Statistics for Windows Version 20 (SPSS, Chicago, IL, USA). Kolmogorov-Smirnov and Shapiro-Wilk tests were used to test normal distribution of the data. As the data (μm) were normally distributed, one-way analysis of variance (ANOVA) and Tukey`s tests were used. P values less than 0.05 were considered significant in all tests.

Results

The mean marginal and internal cement thickness were not significant in all inlay materials ($p > 0.05$).

The marginal cement thickness (μm) was the lowest for IPS group (67.54±10.16) followed by VE (84.09±3.94) and CS (95.18±10.58) (Table 2) ($p > 0.05$).

The internal cement thickness (μm) was the lowest in CS group (54.85±6.94), followed by IPS (60.58±9.22) and VE (77.53±12.13) ($p > 0.05$).

Discussion

This study was undertaken in order to compare the compare the marginal and internal cement thickness of molar inlay restorations made of a variety of CAD/CAM materials using an x-ray micro-CT. Based on the results obtained, since there were no significant difference between the measurement areas (marginal versus internal) in all tested materials, the null hypothesis was accepted.

The non-significant differences between groups could also indicate accurate preparation designs. The geometry of the preparation employed in this study was in accordance with the recommended preparation guidelines for ceramic partial coverage restorations.[27,33,34] In an attempt to standardize the preparation procedures, the same operator working with the same settings and using the dental surveyor prepared the cavities. In addition, the same CAM equipment and software were used to scan the specimens, design the inlays, and mill the restorations.

Clinically acceptable marginal gap of fixed restorations is yet to be formally identified. However, the American Dental Association (ADA) Specification No. 8 states that the thickness of luting cement used to bond a crown should not exceed 40 μm when using different type of luting agents.[37] Although marginal openings in this range are seldom achieved, a 40 μm thickness of the luting cement is widely acknowledged as the clinical goal. According to existing research in this area, marginal/internal gap values between 20 and 200 μm are found largely clinically acceptable.[8,23-28] A review of studies similar to the current research that have employed an x-ray micro-CT technique revealed marginal/internal gaps between 11.86 and 230.53 *μ*m.[15-22] In the present study, 3D marginal and internal mean cement thicknesses of restorations in all material groups ranged between 60.58±9.22 and 95.18±10.58 μm, which is less than 100 μm and, therefore, clinically acceptable.[31,32] Even the highest cement thickness values in this study were less than those reported in previous studies. This could be attributed to the measurement methodology.

Other methods such as silicon weight and density evaluation,[38] the use of a triple scan protocol with a non-contact scanner and specific software to perform a virtual 3D analysis,[39, 40] and micro-CT evaluation,[41] suffer from two major methodological limitations in this domain. The first limitation concerns the number of measurement points where increased number of points on the entire periphery or volume of the restoration can provide a more accurate average assessment of pertinent adaptation. The second methodological limitation relates to the geometric tracking system that defines the limits of the marginal gap measured.[42,43] 3D assessment using X-ray micro-CT in this study successfully overcomes these limitations. The methodology employed represented a non-destructive approach by which it was possible to perform a quantitative analysis of the marginal and internal accuracy of the restoration in a manner that left the tooth intact and provided means through which the measurements could be reproduced at different time intervals.[15-22]

In this study only one type of inlay preparation was assessed. Other preparation designs for inlays or partial coverage restorations made of CAD/CAM materials may show different results and validity of micro-CT should also be verified in other preparation designs. It has to be noted that except for IPS, the other CAD/CAM materials used in this study did not require the sintering. Marginal cement thickness in IPS group was less than those with VE and CS, yet being not significant. Whether less cement thickness in marginal area with IPS is a result of sintering or not need to be investigated in future studies.

Conclusions

Using 3D micro-CT, marginal and internal cement thickness of MOD inlays manufactured using monolithic lithium disilicate, polymer-infiltrated ceramic and nano-ceramic CAD/CAM materials, presented mean values less than 100 μm, which could be considered clinically acceptable.

Acklowledgements

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Conflict of interest

The authors did not have any commercial interest in any of the materials used in this study.

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Captions to tables and legends:

Tables:

Table 1. Brands, abbreviations, manufacturers and batch numbers of the inlay materials used in this study.

Table 2. Mean marginal and internal cement thickness and standard deviations (SD) (µm) for the MOD inlay restorations made of different CAD/CAM materials. For group abbreviations see Table 1.

Figures:

Figure 1 Micro-CT images of cement thickness under the inlays in MOD cavities from axial, occlusal and mesial views.

Tables:

Brand	Manufacturer	Batch Numbers
IPS e-max CAD (IPS)	Ivoclar Vivadent GmbH, Schaan, Liechtenstein	U16405
Vita Enamic (VE)	VITA Zahnfabrik, GmbH & Co, Bad Säckingen, Germany	41960
Cerasmart (CS)	GC Dental Products, Tokyo, Japan	1412081

Table 1. Brands, abbreviations, manufacturers and batch numbers of the inlay materials used in this study.

Experimental Groups	Marginal Cement thickness (±SD) (μm)	Internal Cement thickness (±SD) (μm)
IPS	67.54±10.16	60.58±9.22
VE	84.09±3.94	77.53±12.13
CS	95.18±10.58	54.85±6.94
	$p > 0.05$	$p > 0.05$

Table 2. Mean marginal and internal cement thickness and standard deviations (SD) (μm) for the MOD inlay restorations made of different CAD/CAM materials. For group abbreviations see Table 1.

Figures:

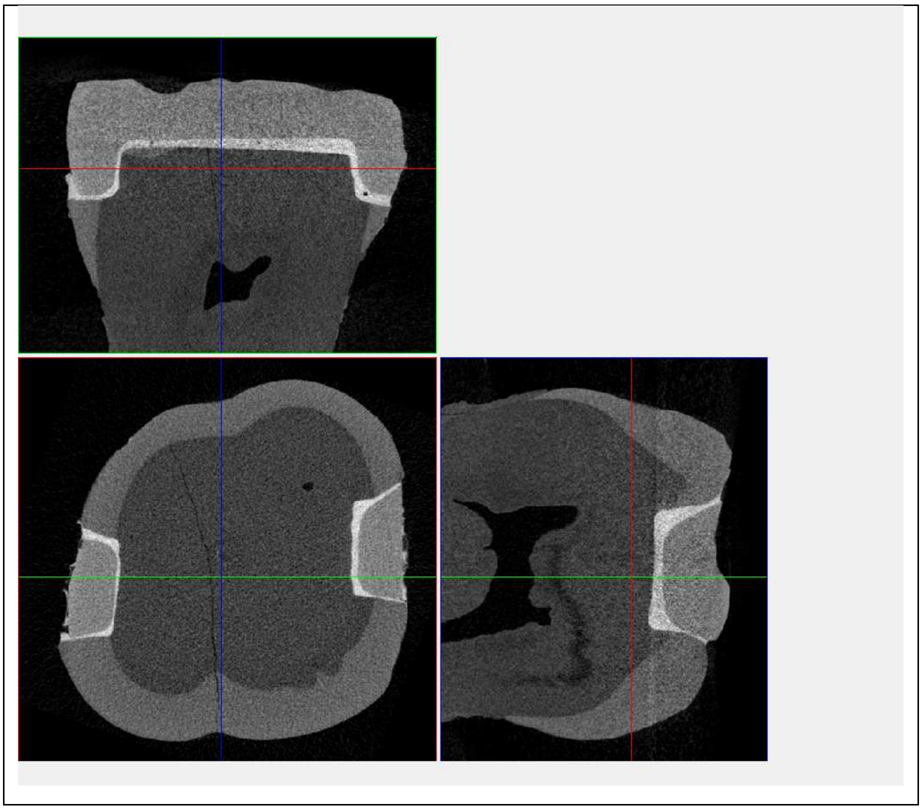

Figure 1 Micro-CT images of cement thickness under the inlays in MOD cavities from axial, occlusal and mesial views.